Partitioning sand transport between channels of a deep river channel bifurcation: Implications for river diversion structures and land building in southern Louisiana

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Abstract

Man-made diversion structures that cut through the levees of the Mississippi River act as channel bifurcations, delivering water and sediment to an otherwise disconnected wetland environment. In this study, the role of diversion depth in controlling the amount of sand that exits from the primary channel during river flooding is examined. We follow the sand fraction because new land built by active sub-deltas of the Mississippi River delta is predominately composed of sand rather than mud. Sand transport is not evenly distributed from the channel bottom to the water surface in large rivers. The highest concentrations of moving sand are located near the bed. This suggests that diversions dug to depths tapping the lowermost portion of the water column might export considerably more sand to the neighboring overbank regions for land building purposes. In order to explore the importance of deep diversions for land building we measured properties of the Atchafalaya River – Grand Lake bifurcation near Morgan City, LA, during high discharge in May, 2009. Grand Lake is the entrance point to the Wax Lake outlet channel and the Wax Lake delta. Persistent growth of this delta over the past 30 years highlights the successful land-building properties of this diversion. Bathymetry defining the geometry of this bifurcation, as well as measurements of flow and sediment transport in its Atchafalaya and Grand Lake branches is used to illustrate the effectiveness of a relatively deep diversion for land building. This case study can be used to evaluate the potential of other river diversions as conduits delivering sediment to neighboring wetlands for rebuilding the Mississippi River delta.

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Background:

Coastal land loss and the drowning of coastal wetlands in Louisiana have reached catastrophic proportions. As documented in Morton et al. [2005], land loss has been occurring at rates near $44km^2/yr$ for the last few decades. In order to maintain an equilibrium delta elevation, the processes of geophysical subsidence, soil compaction, and sea level rise must be balanced by sedimentation. In an unaltered delta system, river avulsions act to distribute sediment and fresh water to topographic lows [Straub et al., 2009]. Periodically, floods break or flow over natural levees, distributing sediment to the surrounding delta top. These processes have been able to maintain surface elevations for Mississippi River delta that are slightly greater than sea level throughout the Cenozoic [Galloway et al., 2000].

Human alterations to the Mississippi River delta have acted to prevent the sedimentation processes that act against land submergence. The river in Louisiana has been locked into its present course by man-made levees that run almost to its mouth, preventing it from changing course and distributing sediment to low lying areas. These man-made levees also act to prevent deposition via overbank flow and crevasse splay formation. Much of the sediment delivered to the mouth of the Mississippi River does not contribute to active land building processes because it spills off of the continental margin into the deeper Gulf of Mexico [Figure 1]. Furthermore, extremely high rates of subsidence have been observed in southernmost Louisiana during the last 70-80 years. While geological rates of subsidence range from 0.3 to 4.4 mm/yr for the last 5,000 years [Morton et al., 2005; Meckel et al., 2006], subsidence rates as high as 18.9 mm/yr have been observed in the last few decades [Meckel et al., 2006]. High rates of subsurface fluid extraction, which lower of fluid pressures and increase compaction of the sedimentary deposit, are concurrent with these high subsidence rates [Figure 2; Morton et al., 2005].

Figure 1. Sediment-charged water exiting the Mississippi River channel at and near the river mouth. The majority of this sediment is deposited in the marine environment rather than on the delta. Some of the sediment spills off of the edge of continental shelf where it is deposited in the deeper Gulf of Mexico [MODIS satellite image, flood of Spring 2008].

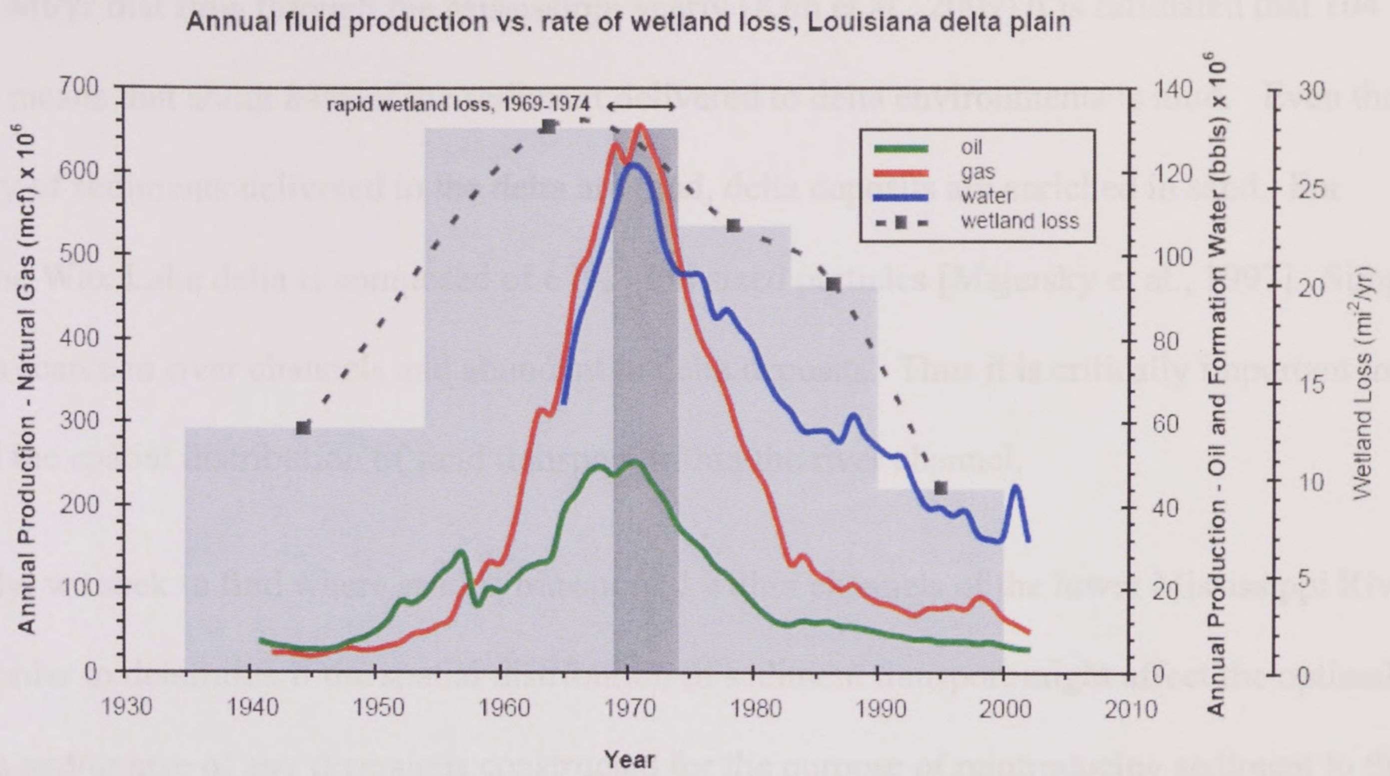


Figure 2. Plot showing correlation of subsurface fluid extraction and wetland loss [from Morton et al. 2005]

Finally, dams have been constructed upstream of the delta since the 1950s, impounding sediment and thereby reducing the total sediment load in the Mississippi River from ~400-500Mt/yr to ~208Mt/yr. Of the 208 Mt/yr, it is estimated that 124 flows into the lower Mississippi and 84 flows into the Atchafalaya River at their bifurcation [Kim et al., 2009; Blum and Roberts, 2009; Allison et al., 2000; Horowitz, 2006]. Even with the reduced sediment load, it is possible to mitigate land loss and create new land in some areas [Kim et al., 2009]. One method for counteracting the combined processes driving land loss in southern Louisiana is the implementation of man-made, controlled diversions. Engineered diversions act to supply sediment and fresh water to disconnected wetland environments, building land and re-introducing favorable salinity gradients. Diversions, however, are extremely expensive, with some costing over 417 million dollars [LaCoast, 2010]. As a consequence, they must be engineered to maximize the amount of sediment that can be distributed onto the delta. One way of ensuring maximum sediment delivery is to understand the sediment transport processes in the Mississippi River system to the highest degree possible.

Of the 124 Mt/yr that flow through the Mississippi yearly [Kim et al., 2009] it is estimated that 104 Mt is mud. This means that about 84% of the sediment delivered to delta environments is mud. Even though the majority of sediments delivered to the delta are mud, delta deposits are enriched in sand. For example, the Wax Lake delta is composed of 67% sand sized particles [Majersky et al., 1997]. Simply put, sand is scarce in river channels and abundant in delta deposits. Thus it is critically important to understand the spatial distribution of sand transport within the river channel.

In this study, we seek to find where sand is transported within channels of the lower Mississippi River system in order to determine if the spatial distribution of sediment transport might affect the optimal dimensions and/or size of any diversions constructed for the purpose of reintroducing sediment to the delta top. Designs for diversions should be based on geometries that have been proven to supply sufficient sediment for substantial land growth. The Wax Lake delta has produced consistent subaerial land growth since 1973, as well as subaqueous deposition beginning around 1950. Prior to growth of the Wax Lake delta, the Atchafalaya River supplied sediment that filled the Atchafalaya basin, including Grand and Six Mile lakes between 1917 and 1960 [Roberts et al., 1980]. By studying sediment transport at the Atchafalaya River – Wax Lake bifurcation [Figures 3 and 4], land building potential for a relatively large and deep diversion in the Mississippi River can be assessed. The results of this study show that sand in suspension is concentrated and transported near to the bed, and that bedform migration on the channel bottom accounts for a significant amount of sand transport. This implies that relatively deep diversions can be more effective than broad shallow diversions at diverting land building sediment to the delta top.

<u>Site Description:</u>

This study was conducted at the Atchafalaya River – Grand Lake bifurcation [Figure 4] during high discharge in May, 2009 [Figure 5]. The Atchafalaya River-Grand Lake bifurcation is located approximately 27 Kilometers upstream from Morgan City, Louisiana. While the Atchafalaya River exits at the Atchafalaya River delta, the discharge from Grand Lake exits at the Wax Lake delta [Figure 3].

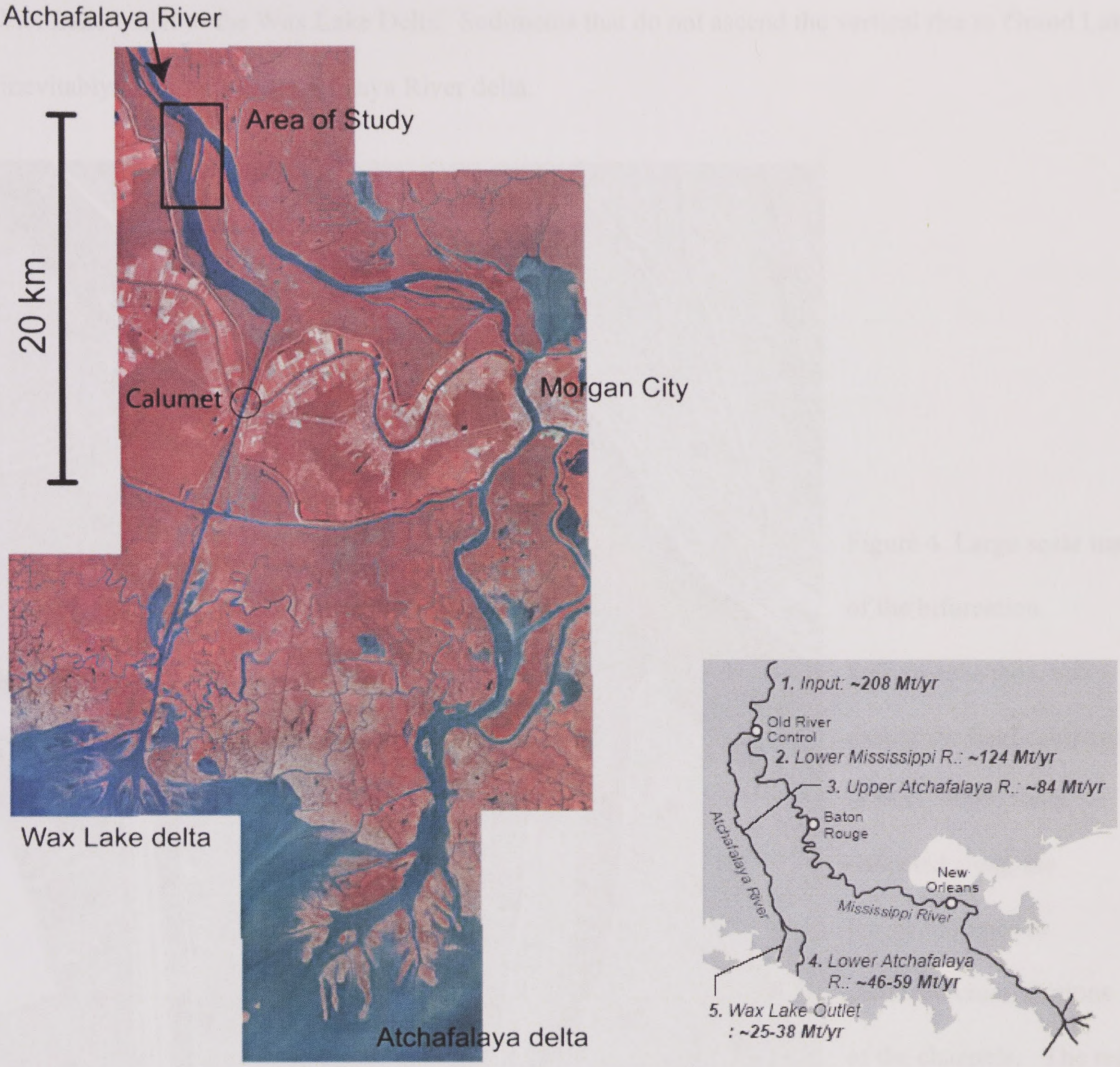


Figure 3. Location map showing the Atchafalaya River – Grand Lake bifurcation, as well as the Wax Lake and Atchafalaya River deltas. The small scale map shows the bifurcation in reference the recognizable Louisiana coastline.

Multibeam bathymetry reveals pertinent features, including a deep Atchafalaya thalweg that is covered by an expansive dune field and a 10 meter high ramp that connects this thalweg to the shallower Grand Lake [Figure 4]. Maximum depth in Grand Lake is approximately 38% of the maximum water depth in Atchafalaya River. Sediments must ascend the ramp that connects the deep channel of the Atchafalaya with Grand Lake via bedform migration or suspended sediment transport before being transported down the Wax Lake outlet to the Wax Lake Delta. Sediments that do not ascend the vertical rise to Grand Lake will inevitably travel to the Atchafalaya River delta.

Figure 4. Large scale map of the bifurcation. Bathymetric data, taken during the field campaign in May, 2009, were collected along the horizontal lines to construct cross-sections of the channels. The red circles corresponding to sites 1-6 represent vertical profiles containing 3-5 suspended- sediment profiles.

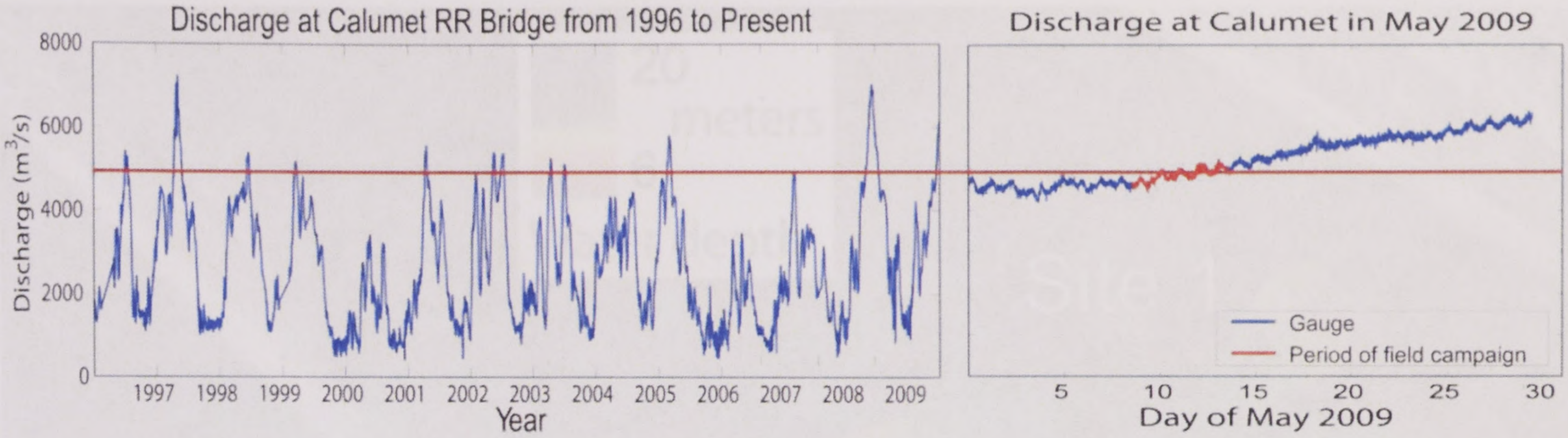


Figure 5. Water discharge at USGS gauging station # 07381590; Wax Lake Outlet at Calumet, LA (figure 3). The right-hand graph highlights water discharge at this site during the May 2009 field study.

Methods:

Bathymetry data of the study area, imaged using a RESON SeaBat 8101 Swath Bathymetry Profiler provide a detailed map of all of the important features in the bifurcation study area including the overall morphologies of both channels, the presence of bed alluvium worked into subaqueous dunes, and exposed channel substrate possessing a variety of erosional marks including flutes and grooves [Figures 4, 6]. Using bathymetry as a guide, suspended-sediment samples were collected using a USGS isokinetic P-63 sampler at anchored positions along the two channel profiles marked in Figure 4. One profile is in the Atchafalaya River upstream of the bifurcation [Figures 6, 7] while the other is in Grand Lake, just downstream of the bifurcation [Figures 8, 9]. Each of these cross-channel profiles consists of three vertical profiles where suspended sediment and velocity data were collected. The P-63 sampler retrieves representative samples of sediment and water at chosen depths in the river, collecting the samples in 1-liter glass jars. Between 3 and 5 suspended sediment samples were collected at each profile. The locations of these samples within the water column, closely spaced near channel bottoms where sand transport is greatest, are marked in figures 7 and 9.

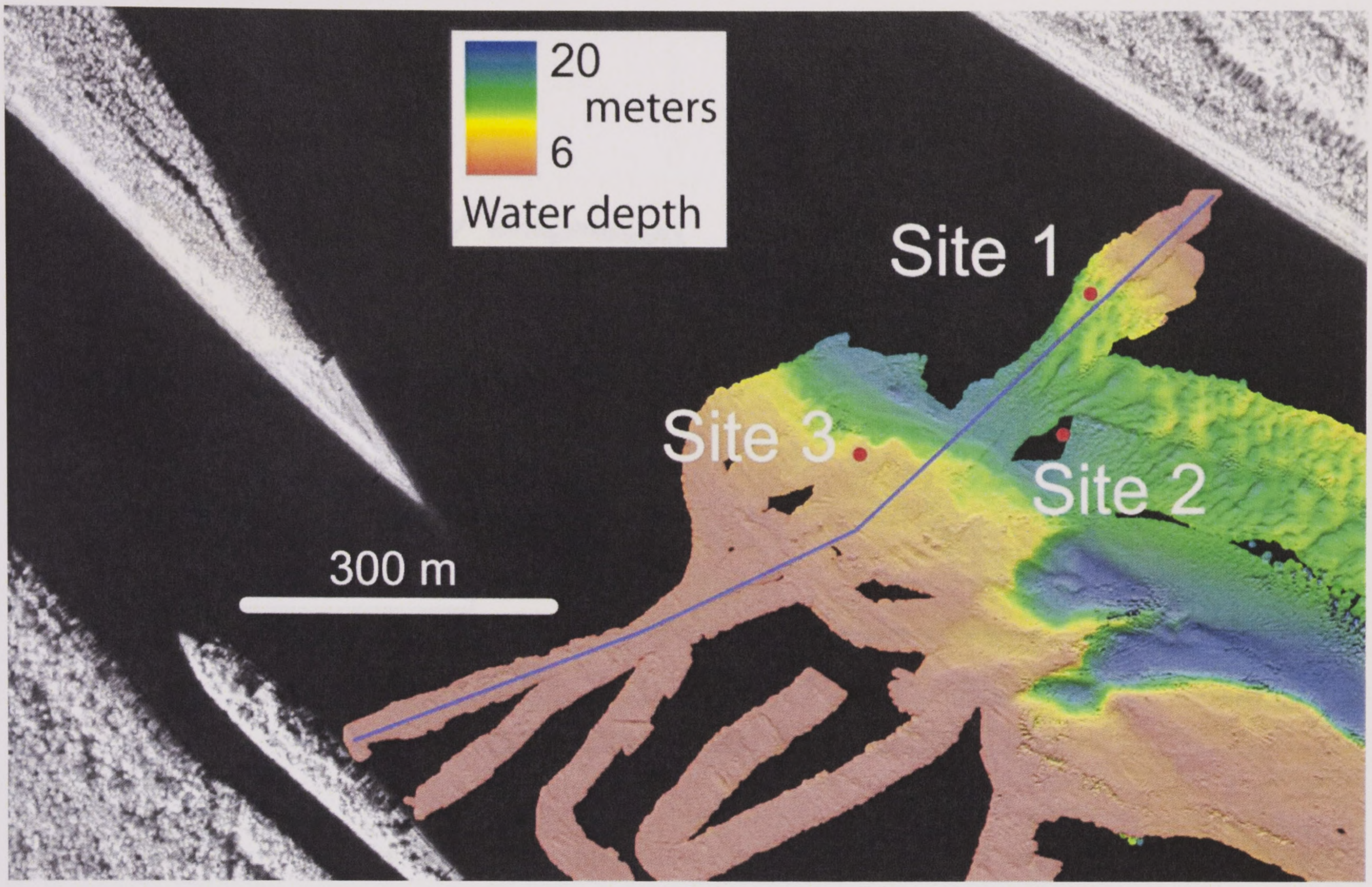


Figure 6. Close up view of upstream transect in the Atchafalaya River from figure 4. Sites 1, 2, and 3 are representative of vertical profiles, each containing 5 suspended sediment samples at varying depths. Scour marks are visible on the southern edge of the channel, while trains of dunes are seen on the northern edge. The solid line across the channel represents the line from which bathymetry data were collected to create the cross-section in figure 7.

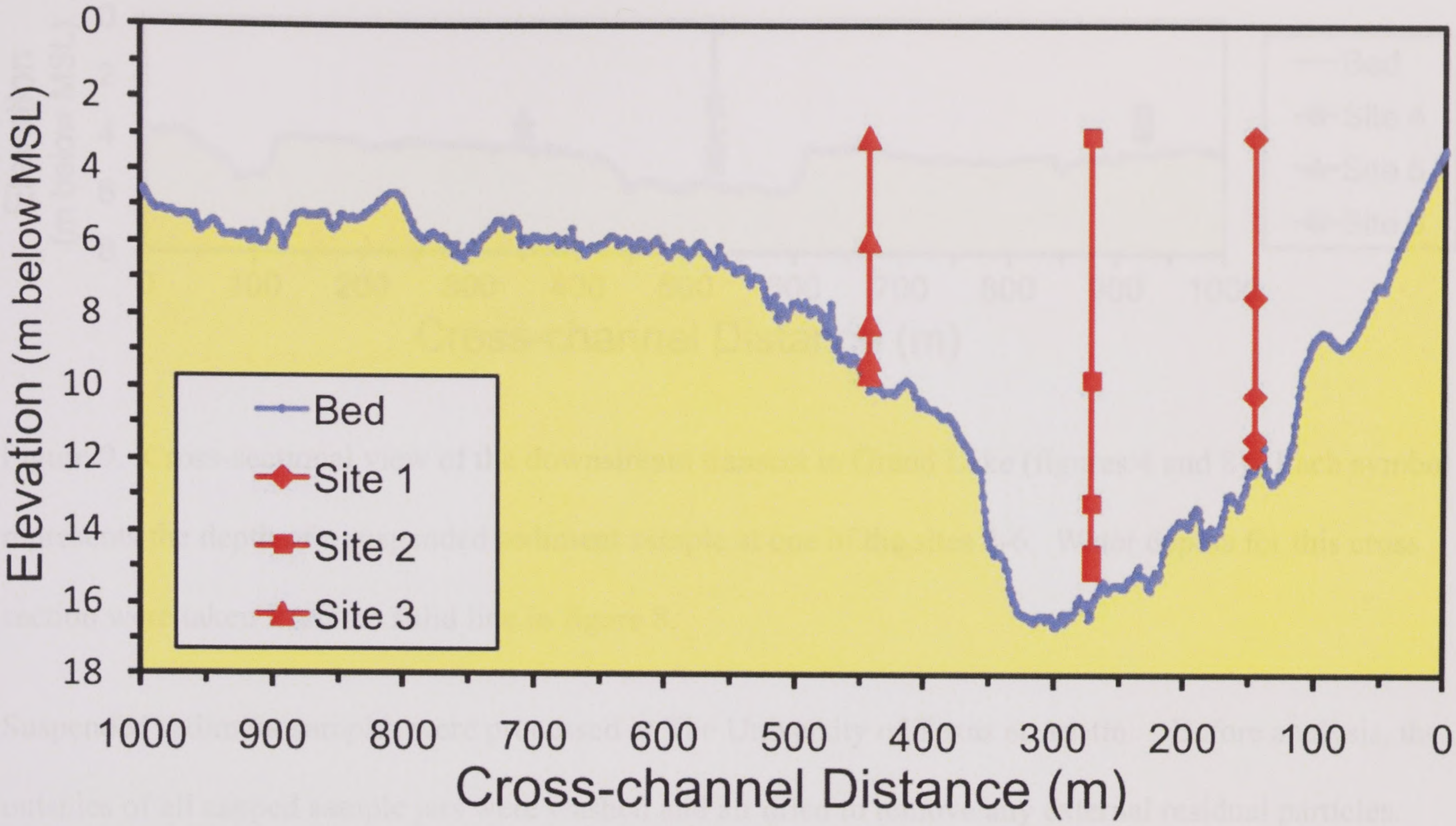


Figure 7. Cross-sectional view of the upstream transect in the Atchafalaya River (figures 4 and 6). Each symbol represents the depth of a suspended sediment sample on one of the sites 1-3. Water depths for this cross section were taken from the solid line in figure 6.

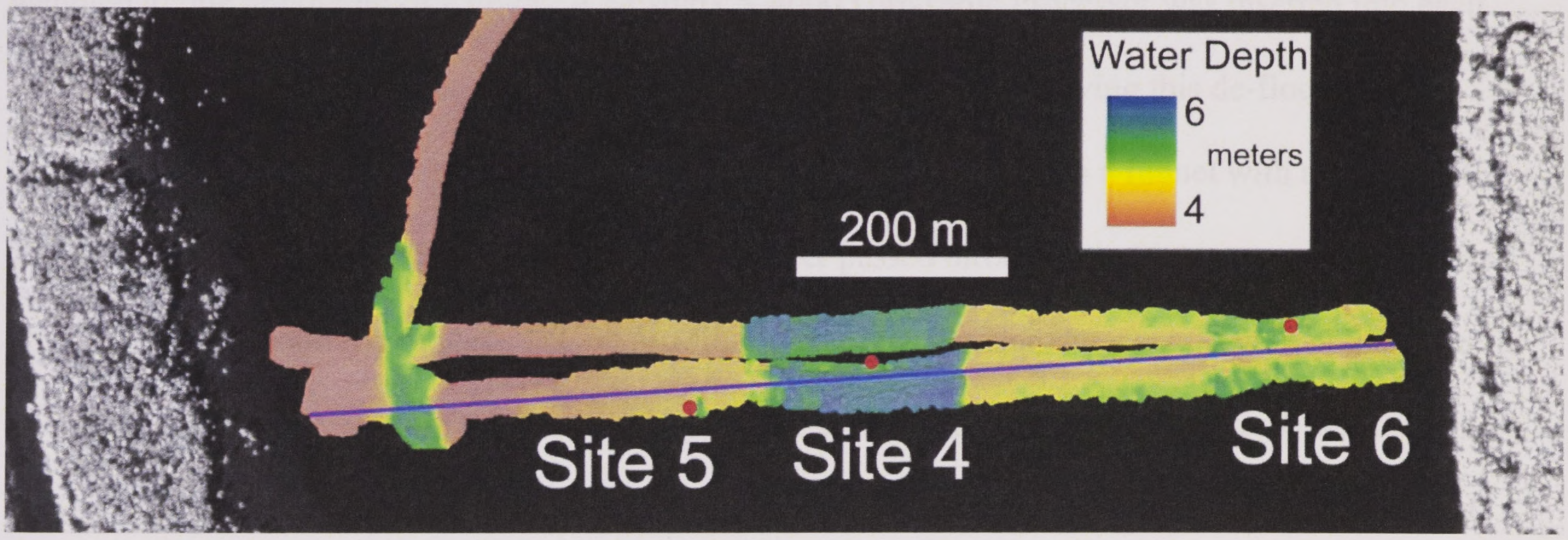


Figure 8. Close up view of downstream transect in Grand Lake from figure 4. Sites 4, 5, and 6 are representative of vertical profiles, each containing 3-5 suspended sediment samples at varying depths. The solid line across the channel represents the line from which bathymetry data were collected to create the cross-section in figure 9.

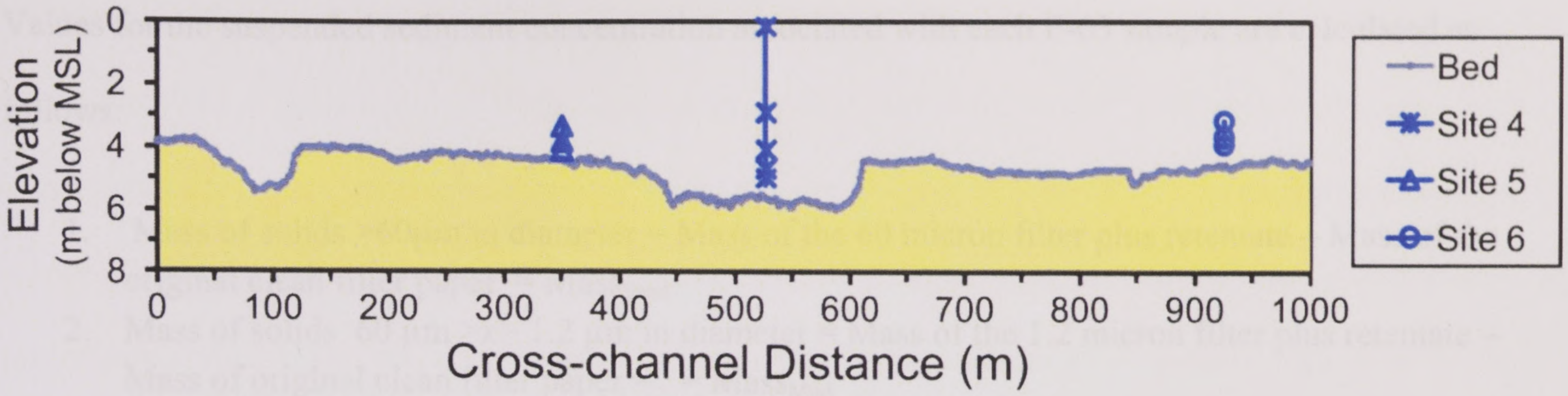


Figure 9. Cross-sectional view of the downstream transect in Grand Lake (figures 4 and 8). Each symbol represents the depth of a suspended sediment sample at one of the sites 4-6. Water depths for this cross section were taken from the solid line in figure 8.

Suspended sediment samples were processed at The University of Texas at Austin. Before analysis, the outsides of all capped sample jars were washed and air dried to remove any external residual particles. Particle filter papers were weighed to one ten-thousandth of a gram and assigned numbers that correspond to the sample number and filter mesh size. Each sample had two filter papers, one with a mesh size of 60 um and another with a mesh size of 1.2 μm. Sample jars containing the water plus sediment sample were weighed to one hundredth of a gram. A Misonix S-4000 Ultrasonic Processor was inserted into each sample jar to break up any flocculated clay and silt sized particles. Following this de-flocculation procedure the sediment water mixture was poured from sediment jars into a funnel with a 60 μm filter. The water plus particles smaller than 60 μm in diameter passed through this filter, into a flask that was positioned underneath the funnel. The 60 μm filter paper plus its retentate were dried in preparation for weighing and grain-size analysis. The remaining water and sediments were poured from the flask into a vacuum assisted filtration system with a 1.2 μm filter [Figure 10]. Retentate on this filter was dried under a heat lamp to remove residual water from the mud. No significant amounts of solids were able to pass through the 1.2 μm filters. Dried filters with sediment retentate were weighed to one ten-thousandth of a gram. Empty clean sample jars were weighed to one-hundredth of a gram.

Values for the suspended sediment concentration associated with each P-63 sample are calculated as follows:

1. Mass of solids >60μm in diameter = Mass of the 60 micron filter plus retentate – Mass of the original clean filter paper = $Mass_{Sand}$
2. Mass of solids 60 μm >x> 1.2 μm in diameter = Mass of the 1.2 micron filter plus retentate – Mass of original clean filter paper = = $Mass_{Mud}$
3. Mass of all solids = $Mass_{Sand}$ + $Mass_{Mud}$ = $Mass_{TotalSed}$
4. Mass of water = Mass of sample jar plus water and sediment – $Mass_{TotalSed}$ – Mass of clean dry sample jar = $Mass_{Water}$
5. Volume of suspended sand = $Mass_{Sand}$/2.65 g/ml = Vol_{Sand}
6. Volume of total suspended solids = $Mass_{TotalSed}$/2.65 g/ml = $Vol_{TotalSed}$
7. Volume of water = $Mass_{Water}$/0.998 g/ml = Vol_{Water}
8. Volume concentration of suspended sand = Vol_{Sand}/(Vol_{Water} + Vol_{Sand})
9. Volume concentration of total suspended solids = $Vol_{TotalSed}$/(Vol_{Water} + $Vol_{TotalSed}$)

Figure 10. Suspended sediments and water are poured into the top container, pass through the filter (at the same level as the clamp), and water is collected in the flask at the bottom. The process is repeated with vacuum assistance to capture sediments smaller than 60.μm.

Grab samples of channel-bed material were collected at or near most of the suspended sediment profile locations as well as other areas of likely importance, such as dunes fields along the topographic rise from the deep Atchafalaya channel of the shallower Grand Lake [Figure 11]. A Retsch-Technology Camsizer was used to obtain grain size data for these grab samples and suspended materials >60 μm in diameter. Plots of cumulative grain-size distribution were adjusted to include the mass of solids < 60 μm in diameter for suspended sands. Sandy bed material did not contain significant solids < 60μm.

Fluid velocities were measured using an Acoustic Doppler Current Profiler at all positions where suspended sediment profiles were collected [sites 1 – 6, Figures 6 – 9]. Water and suspended-sediment discharge estimates were calculated using these current velocities, the cross sectional areas of the two channels, and the suspended-sediment concentrations. The cross sectional area for each channel, calculated from the measured bathymetry, was divided into sections based on proximity to the profiling sites. Multiplication of cross sectional area (m^2) by average streamwise velocity (m/s), yields water discharge (m^3/s) [Figure 12]. Multiplication of water discharge by the dimensionless suspended-sediment volume concentration (total or sand) gives the suspened-sediment discharge in m^3/s.

Figure 11. Grab samples from the Atchafalaya. The upper grab sample is from the rise leading up to grand lake, while the lower is about 4900 meters into Grand Lake from the bifurcation. The large chunks in the upper sample were ripped up during collection, and the pebbles are thought to be reworked and not transported in the system. Large particles like these were not included in grain size plots.

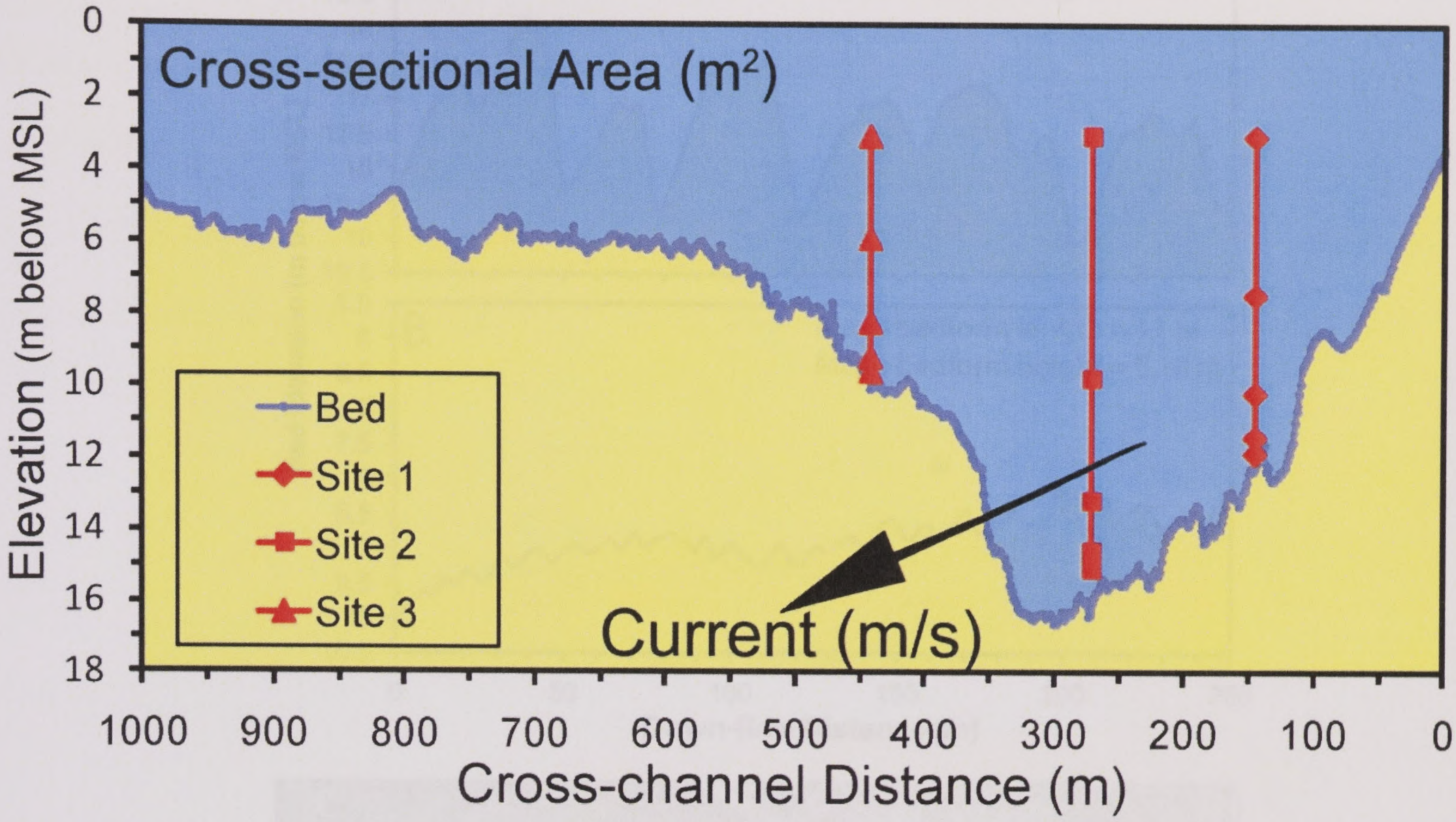


Figure 12. Illustration of discharge calculation. Discharge is cross-sectional area (m^2) multiplied by the average streamwise velocity (m/s).

Bedform Transport:

Multiple dune fields were observed in both the Atchafalaya River and Grand Lake [Figure 13]. Bathymetric data was taken continuously at suspended sediment collection sites while the boat was anchored. At site 2 enough bedforms were present to measure their movement during the data collection period. Bathymetry data were post processed in ArcMap 9.3 to provide elevation profiles of the bedforms at throughout time along a common line. Bedform translation was measured using the position of the dune crest at times t_1 and t_2 [Figure 14]. Topographic data necessary to measure dune translation is only available at profiling site 2 [Figure 6]. The time series at this site was a bathymetry swath running oblique to the streamwise direction. Dunes moved from 0.6 m to 1.07 m along this swath in 13 minutes, but because the angle, Θ, between this swath and the trace of dune crests varied between 5-15°, the translation distances ranged from 0.05 m and 0.28 m in the down-stream direction.

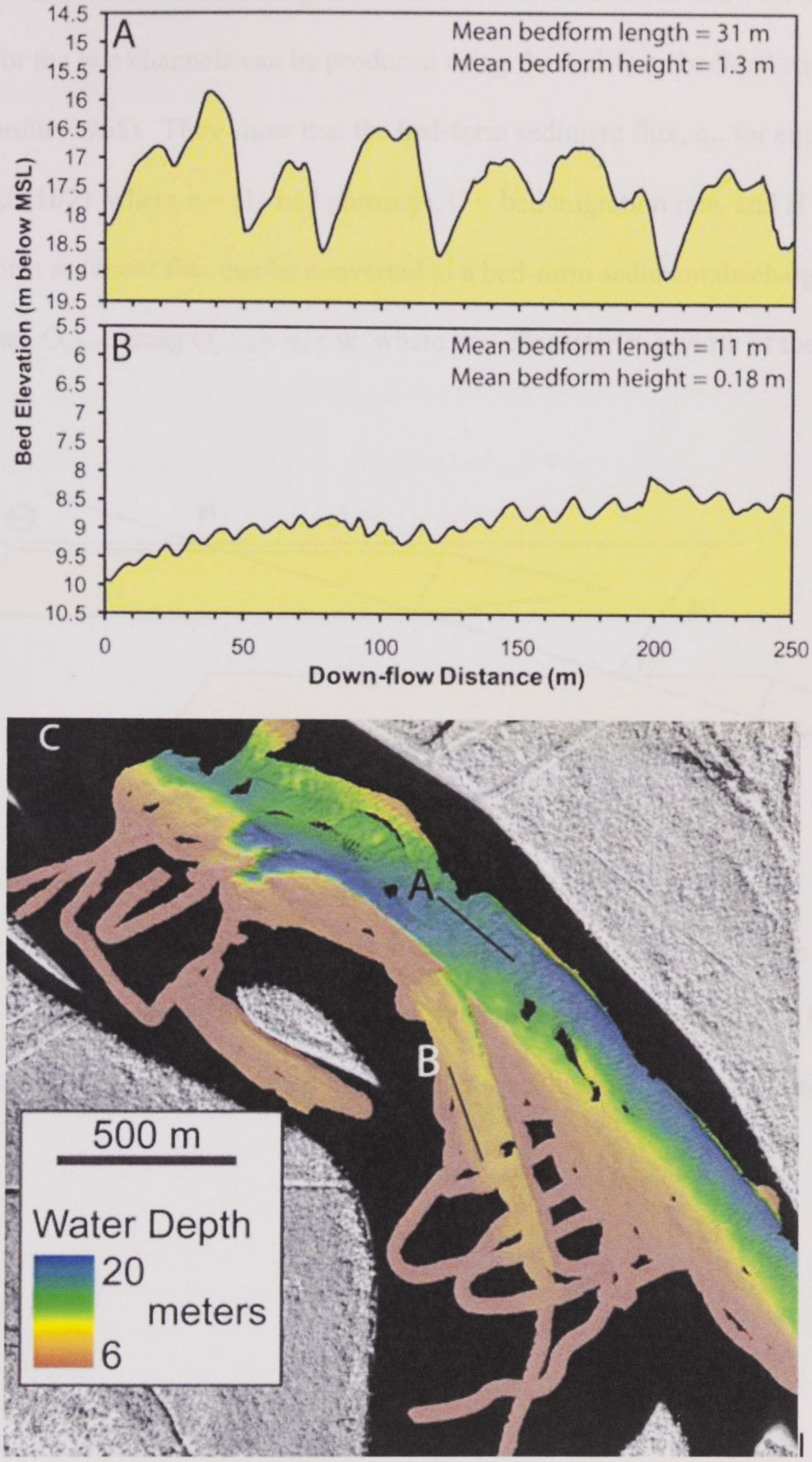


Figure 13. Streamwise bedform profiles for (A) the Atchafalaya River thalweg and (B) the ramp connecting the Atchafalaya and Grand Lake channels (C) Large scale location map showing the location of profiles A and B within the bifurcation.

These distances are associated with dune migration rates between 0.24 m/hr and 1.28 m/hr. Estimates of bed-material load for the two channels can be produced using the bed-form bedload equation of Simons, Richardson and Nordin (1965). They show that the bed-form sediment flux, q_s, for equilibrium bedforms is defined as $q_s = \varepsilon_b C(H/2)$ where ε_b= (1- bed porosity), C = bed migration rate, and H = mean bed-form height. This bed-form sediment flux can be converted to a bed-form sediment discharge that is equal to the bed-material load, $Q_{s\text{-}bed}$, using $Q_{s\text{-}bed} = q_s \times w$, where w = characteristic width of the dune field.

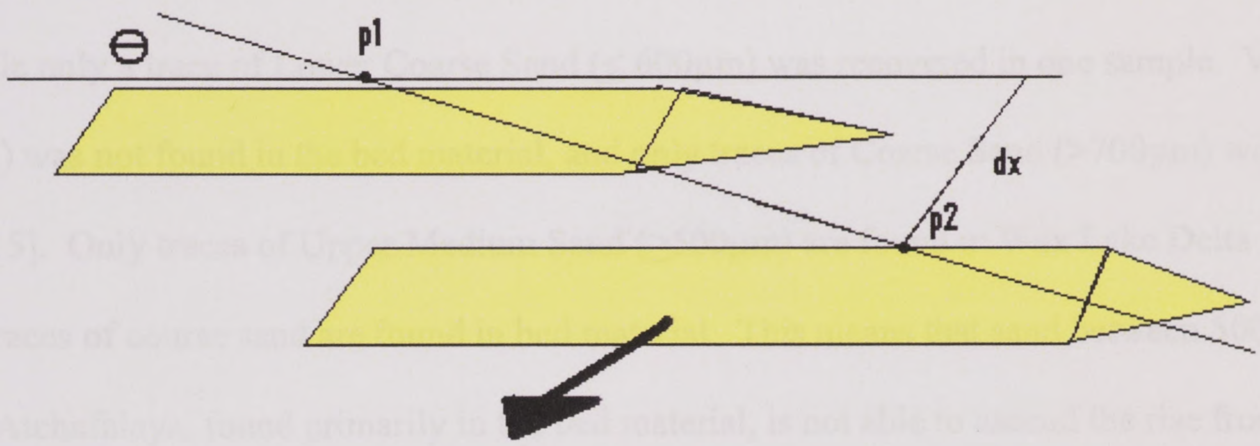


Figure 14. Illustration of method used to calculate dune migration. Positions p_1 and p_2 define the location of a dune crest line at times t_1 and t_2, Θ is the angle between the bathymetry swath and the dune crest line, and dx is the distance the bedform has moved in the streamwise direction between t_1 and t_2 [$(p_2-p_1)\sin(\Theta) = dx$].

Results:

Grain Size of Suspended versus Bed-Material Sand:

There was no resolvable difference between the size distributions for suspended sand measured in the Atchafalaya and Grand Lake channels, while the sand composing the active bed material was somewhat coarser in the Atchafalaya River. The range in measured sand sizes is presented in Figure 15. In this discussion, particles above the 95th percentile or below the 5th percentile are referred to as trace amounts. The coarsest sediment found in every suspended sediment sample was Upper Fine Sand (≤ 250 µm in diameter), while only a trace of Lower Coarse Sand (≤ 600µm) was recovered in one sample. Very fine sand (<125µm) was not found in the bed material, and only traces of Coarse Sand (>700µm) were found there [Figure 15]. Only traces of Upper Medium Sand (≥500µm) are found in Wax Lake Delta [Baitis, 2008], while traces of course sand are found in bed material. This means that sand between 500µm and 700µm in the Atchafalaya, found primarily in the bed material, is not able to ascend the rise from the main channel of the Atchafalaya to Grand Lake. All suspended sizes found at the bifurcation are observed in the delta deposits [Baitis, 2008].

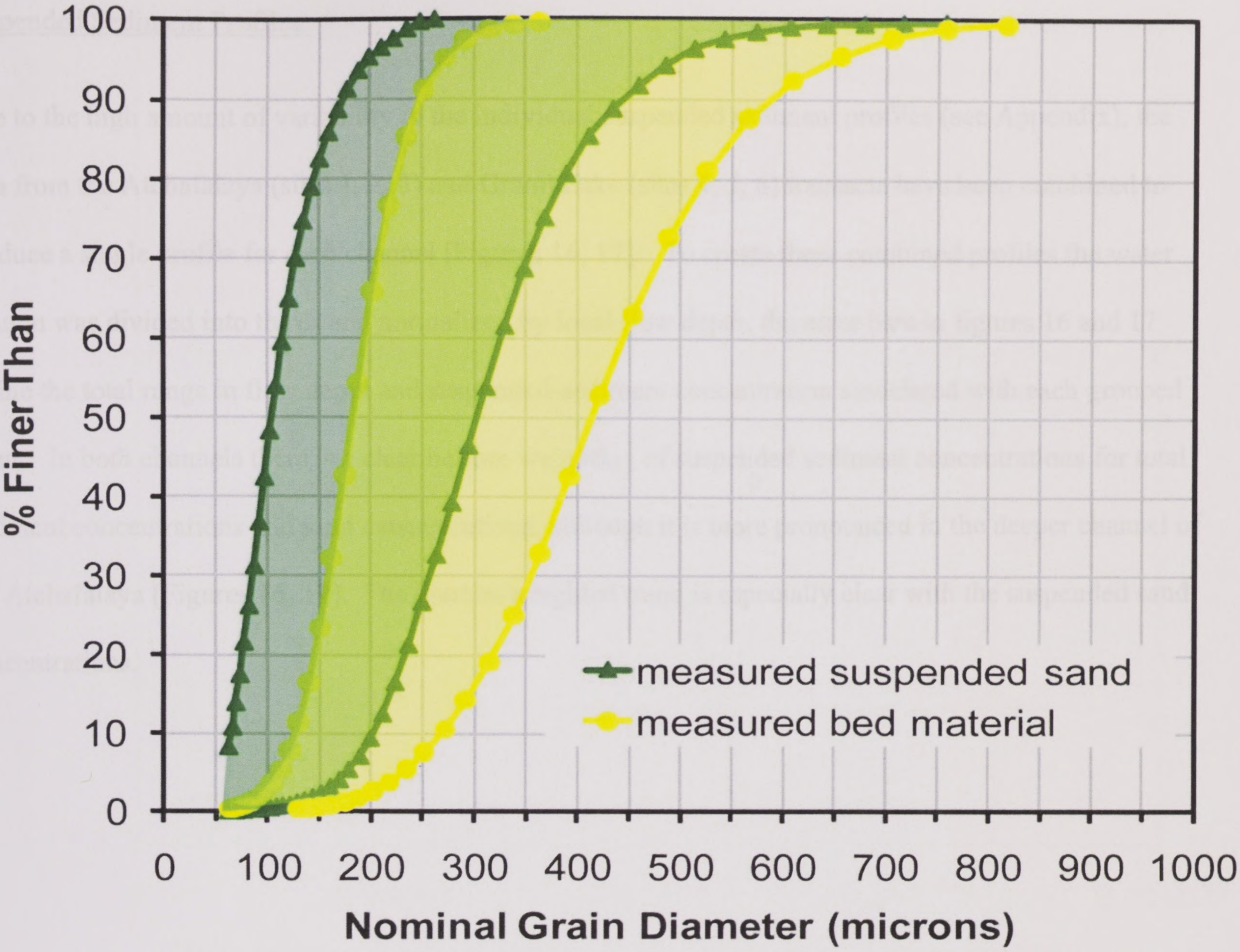


Figure 15. Total range in size of suspended sand and bed sand measured in the Atchafalaya and Grand Lake channels. Grain-size data was analyzed using a Retsch-Technology Camsizer. Mud fractions are not included here.

Suspended Sediment Profiles:

Due to the high amount of variability in the individual suspended sediment profiles (see Appendix), the data from the Atchafalaya (sites 1, 2, 3) and Grand Lake (sites 4, 5, 6) transects have been combined to produce a single profile for each channel [Figures 16, 17]. To create these combined profiles the water column was divided into thirds and normalized by local flow depth; the error bars in figures 16 and 17 define the total range in flow depth and suspended-sediment concentration associated with each grouped point. In both channels there is a clear bottom weighting of suspended sediment concentrations for total sediment concentrations and sand concentrations, although it is more pronounced in the deeper channel of the Atchafalaya [Figures 16, 17]. The bottom-weighted trend is especially clear with the suspended sand concentrations.

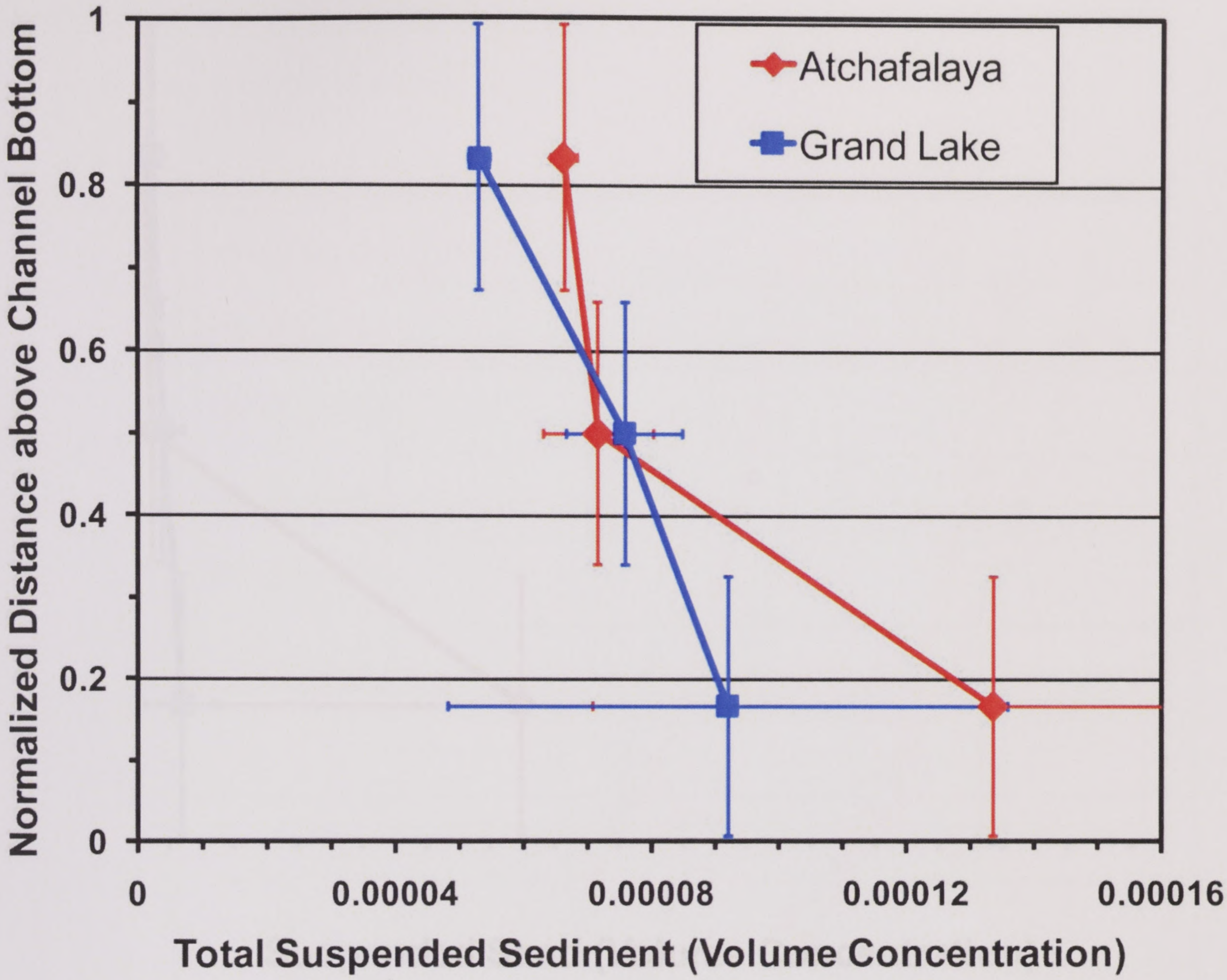


Figure 16. Average values for total suspended-sediment concentration in the Atchafalaya and Grand Lake channels. Values for the Atchafalaya are obtained from sites 1-3 while Grand Lake values are from sites 4-6. Vertical error bars represent the range in normalized local flow depth, while horizontal error bars represent the range in concentrations for those depths.

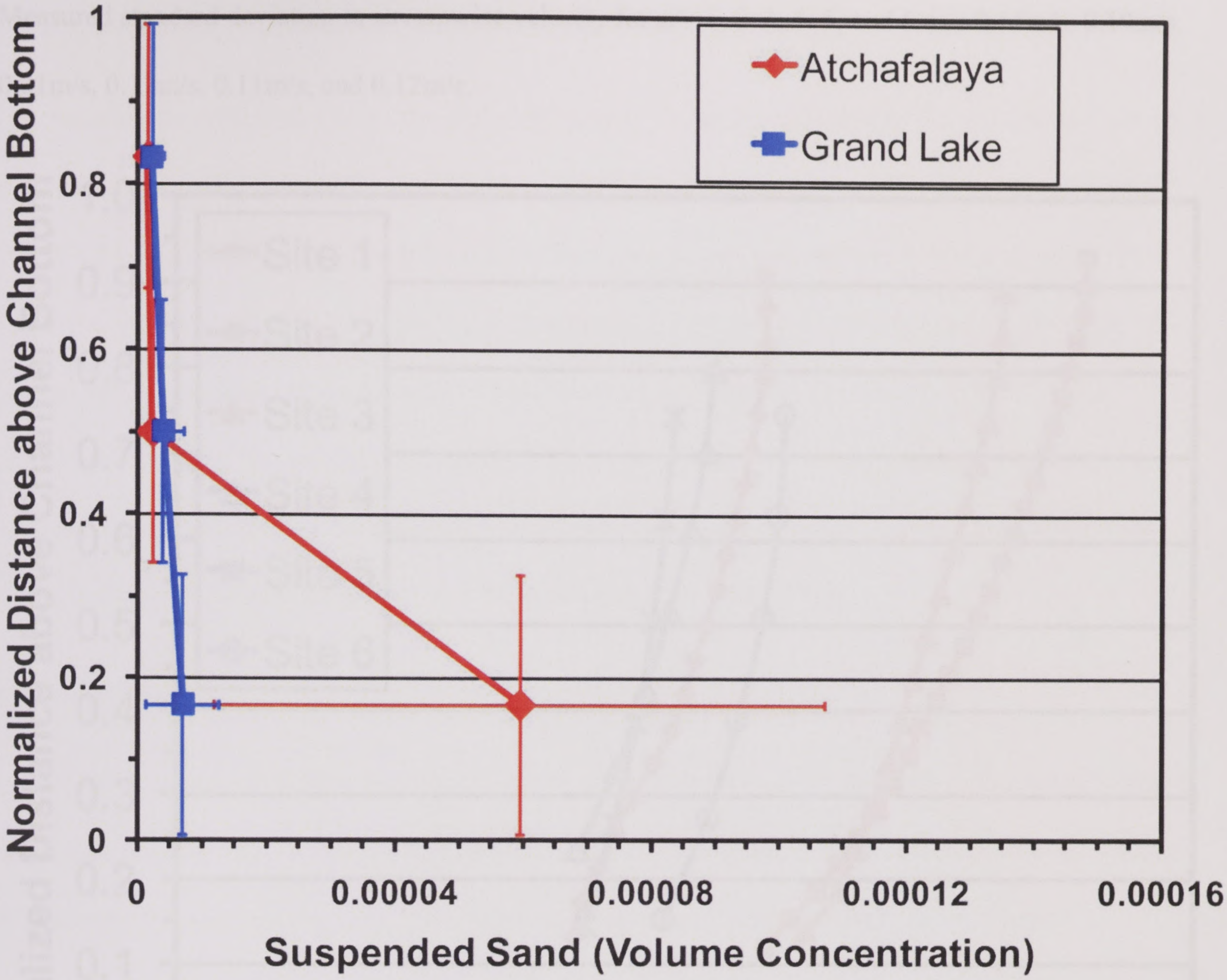


Figure 17. Average values for suspended-sand concentration in the Atchafalaya and Grand Lake channels. Values for the Atchafalaya are obtained from sites 1-3 while Grand Lake values are from site 4-6. Vertical error bars represent the range in normalized local flow depth, while horizontal error bars represent the range in concentrations for those depths.

Velocity Profiles:

Profiles of mean streamwise velocity were taken in both channels using an Acoustic Doppler Current Profiler. Velocities were measured at each of the anchored position. Substantially higher fluid velocities at sites 2 and 3, versus site 1 [Figure 18] document the high velocity core of the Atchafalaya River. Standard deviation in flow velocity at the 6 sites was relatively constant with respect to flow depth.

Measured standard deviation in streamwise velocity for site 1, 2, 3, 4, 5, and 6 was 0.15m/s, 0.19m/s, 0.21m/s, 0.12m/s, 0.11m/s, and 0.12m/s.

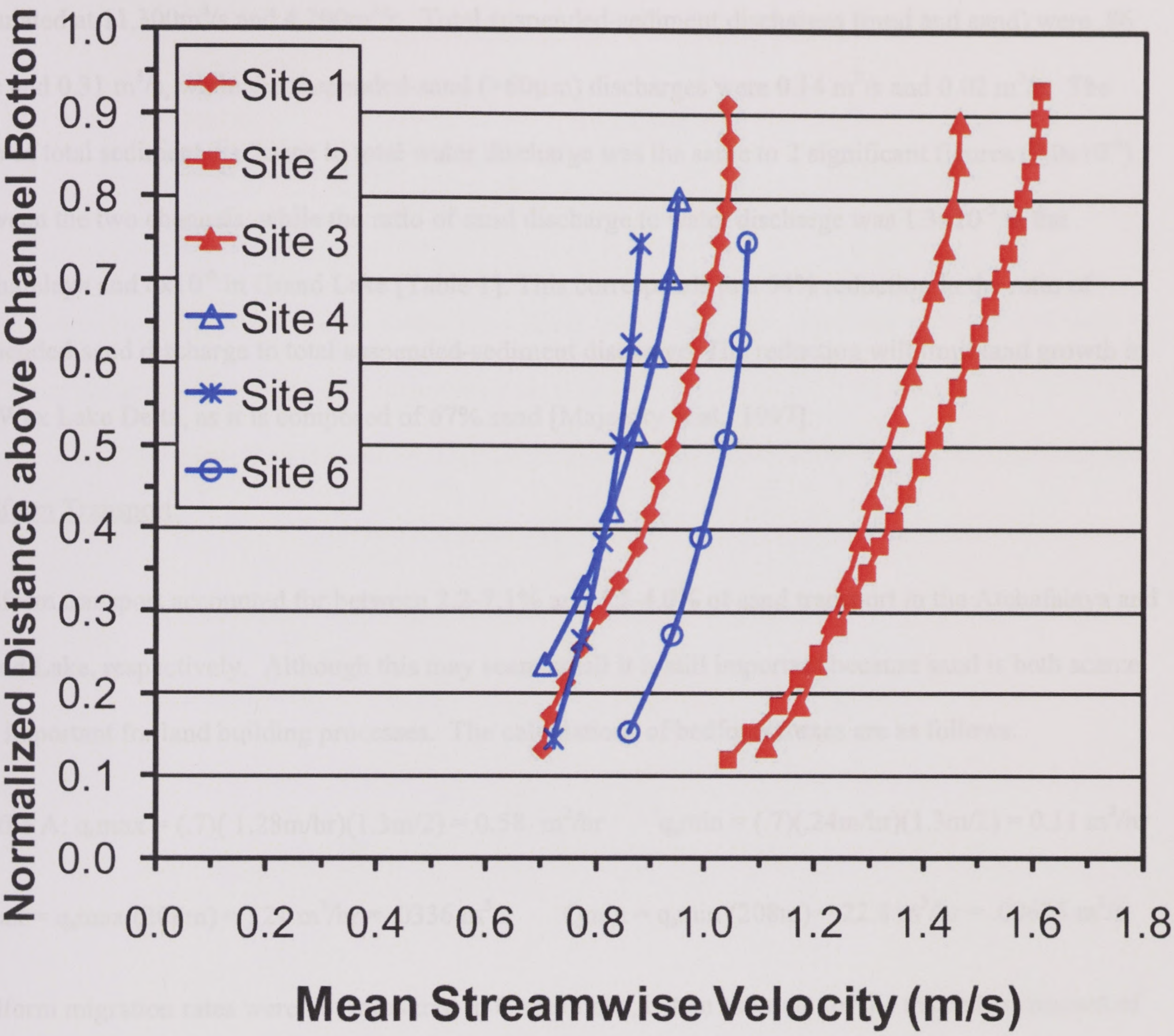


Figure 18. Streamwise velocity profiles for the Atchafalaya and Grand Lake channels at sites 1-6 [Figures 6 & 8]. Higher fluid velocities at sites 2 and 3 versus 1 document the high velocity core of the Atchafalaya River.

Water and Suspended-Sediment Discharge Estimates:

Using the methods explained earlier, the water discharges for the Atchafalaya River and Grand Lake were calculated at 11,300m^3/s and 4,200m^3/s. Total suspended-sediment discharges (mud and sand) were .86 m^3/s and 0.31 m^3/s, while the suspended-sand (>60μm) discharges were 0.14 m^3/s and 0.02 m^3/s. The ratio of total sediment discharge to total water discharge was the same to 2 significant figures (7.0×10^{-5}) between the two channels, while the ratio of sand discharge to water discharge was 1.3×10^{-5} in the Atchafalaya and 6×10^{-6} in Grand Lake [Table 1]. This corresponds to a 54% reduction in the ratio of suspended-sand discharge to total suspended-sediment discharge. The reduction will limit land growth in the Wax Lake Delta, as it is composed of 67% sand [Majersky et al., 1997].

Bedform Transport:

Bedform transport accounted for between 2.2-7.1% and 1.2-4.0% of sand transport in the Atchafalaya and Grand Lake, respectively. Although this may seem small it is still important because sand is both scarce and important for land building processes. The calculations of bedform fluxes are as follows:

Profile A: $q_s max = (.7)(1.28m/hr)(1.3m/2) = 0.58\ m^2/hr$ $\quad$ $q_s min = (.7)(.24m/hr)(1.3m/2) = 0.11\ m^2/hr$

$Qmax = q_s max\ (208m) = 121\ m^3/hr = .0336\ m^3/s$ $\quad$ $Qmin = q_s min\ (208m) = 22.8\ m^3/hr = .00635\ m^3/s$

Bedform migration rates were not measured in Grand Lake, but an estimate for the maximum amount of sand transport associated with the moving bedforms there can be obtained by using the rates for dunes in Atchafalaya River where both current velocities and suspended-sand transport were measurably higher.

Profile B: $q_s max = (.7)(1.28m/hr)(.18m/2) = .080\ m^2/hr$ $\quad$ $q_s min = (.7)(.24m/hr)(.09m) = .015\ m^2/hr$

$Qmax = q_s max\ (200m) = 16.1\ m^3/hr = .00447\ m^3/s$ $\quad$ $Qmin = q_s min\ (200m) = 3.04\ m^3/hr = .000845\ m^3/s$

Water and Sediment partitioning between the two channels:

	Atchafalaya	Grand Lake
Qwater	11300 m3/s	4200m3/s
Qsed_total	.86m3/s	0.31m3/s
Qsand	0.1483m3/s	0.0234m3/s
Qsed_total/Qwater	0.000076	0.000074
Qsand/Qwater	0.000013	0.000006

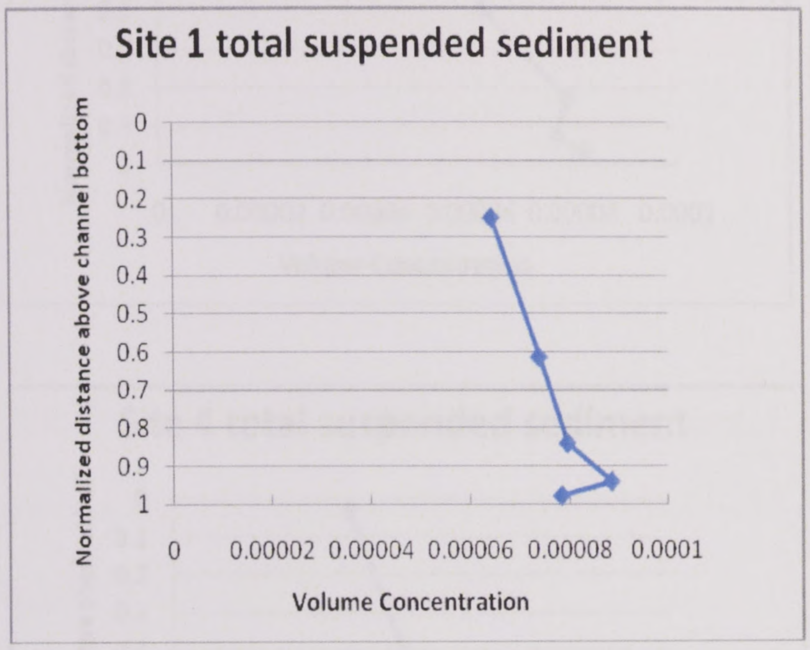
Table 1: Discharge estimates for the Atchafalaya River and Grand Lake. The total sediment discharge a fraction of water discharge did not change for either channel, but there was a 54% reduction in the amount of sand discharge as a fraction of water discharge. Qsand values account for both suspended and bed sand discharges.

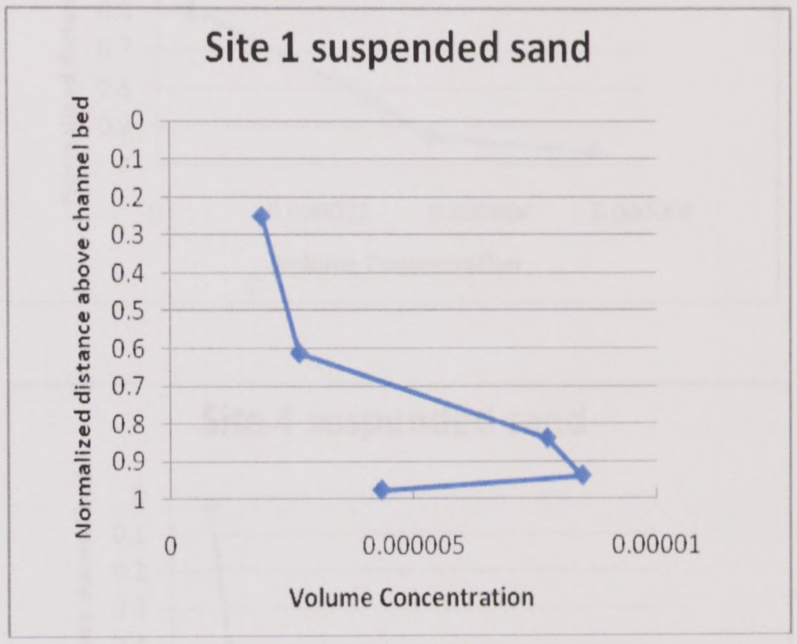
Implications/Conclusions:

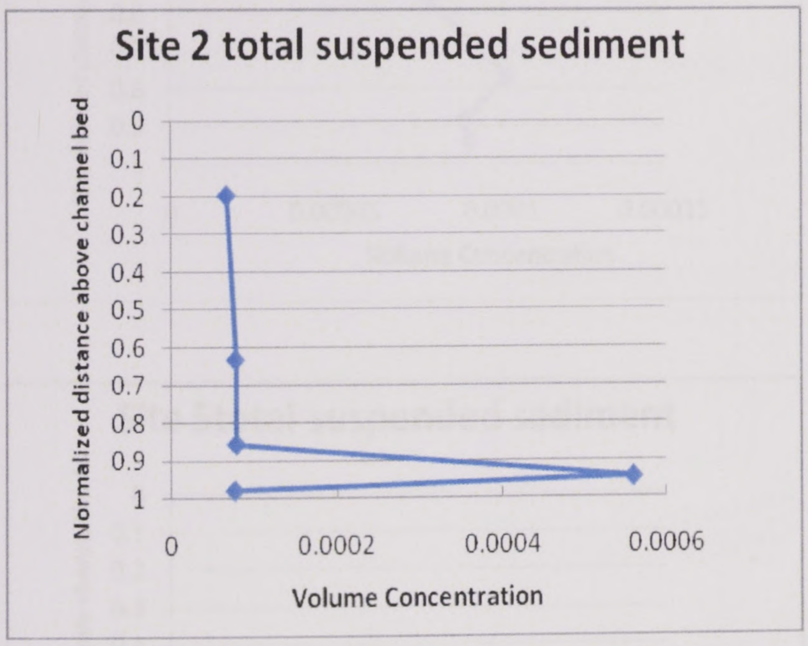
Traditional designs of diversions, which only divert the uppermost portions of flow may not be as effective at building land in subsiding deltas as those which divert deep portions of the flow. Suspended sediment is concentrated near to the river bed, especially with respect to particles sized >60μm. Because of this vertical distribution of suspended sand, the amount of suspended sand contained in a given volume of water from near the surface will not contain as much sand as that of an identical volume near the river bed. In addition, bedform transport also comprises a significant portion of sand transport in large river systems, which means that effective diversions will allow some flux of bedforms where they are present. There is a 54% reduction in the ratio of sand discharge to water discharge from the Atchafalaya to Grand Lake. At this bifurcation 38% of the Atchafalaya is tapped by Grand Lake. We can expect the ratio of sand discharge to water discharge significantly decrease with decreases in tapping fraction. Because the tapping depth of diversions has such a profound effect on the amount of sand delivered to wetland sites, it is a critical component of diversion design. Tapping depth should be considered in all stages of diversion design and development.

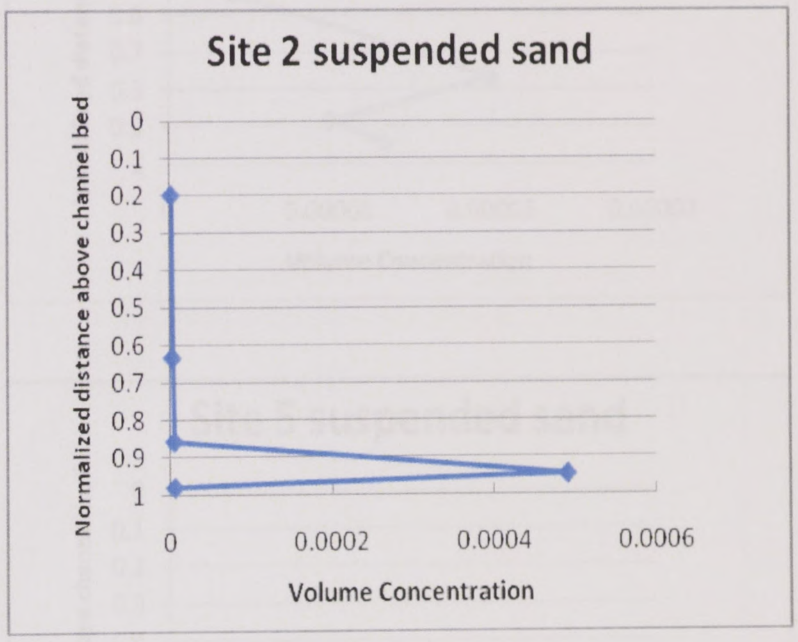
Appendix

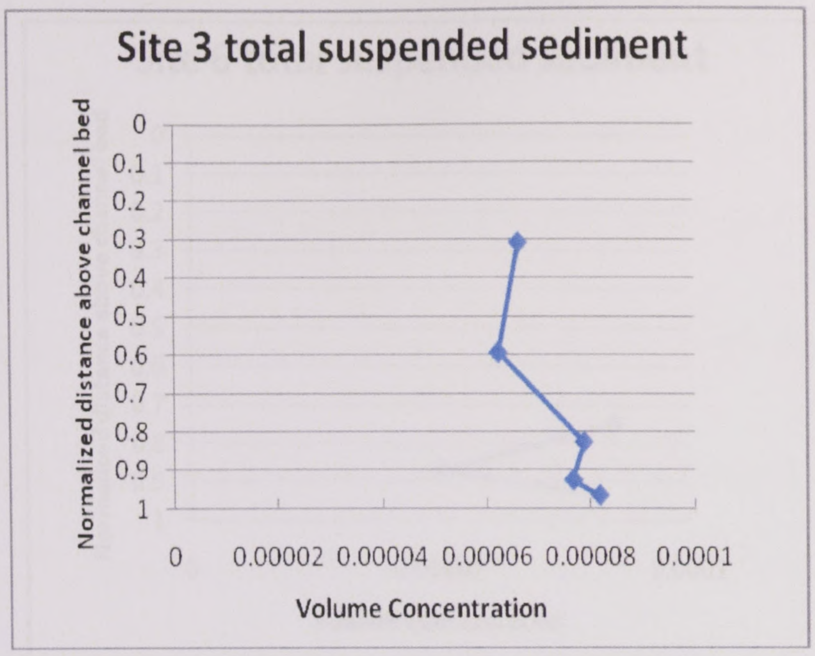
Individual suspended sediment concentration profiles for sites 1-6. Volume concentrations are dimensionless volume ratios (L/L).

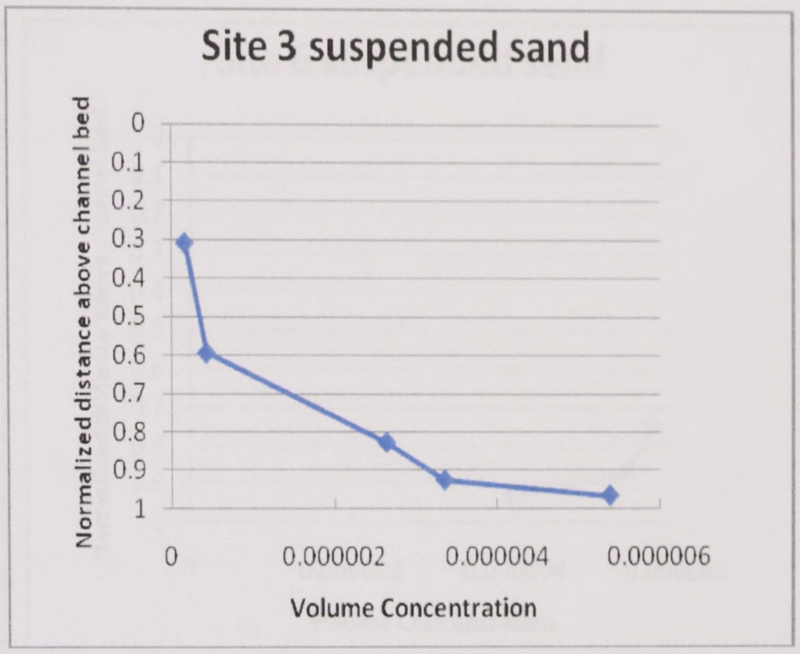


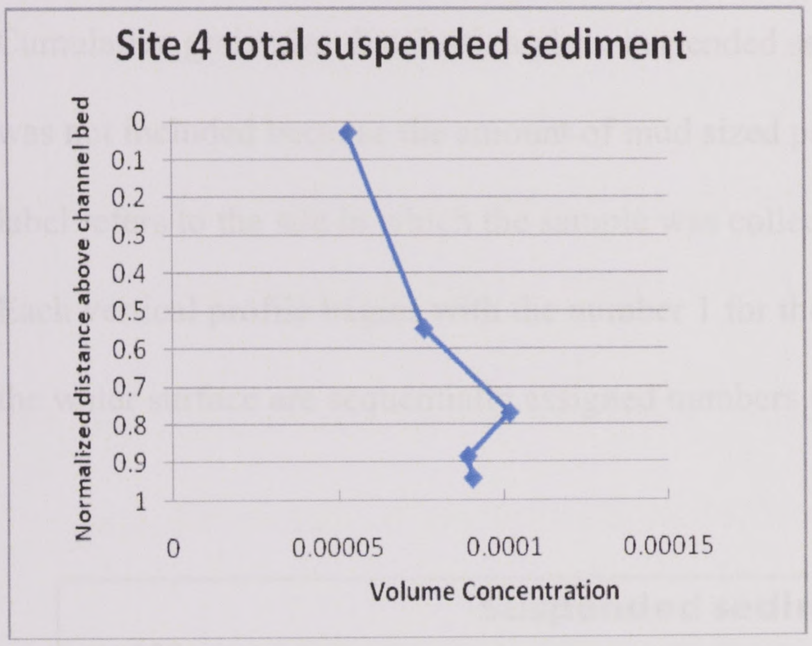


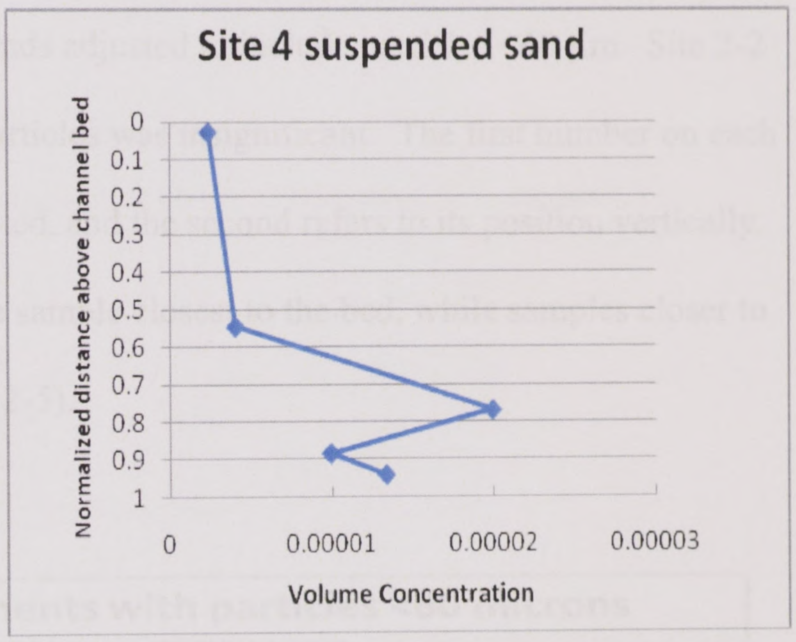


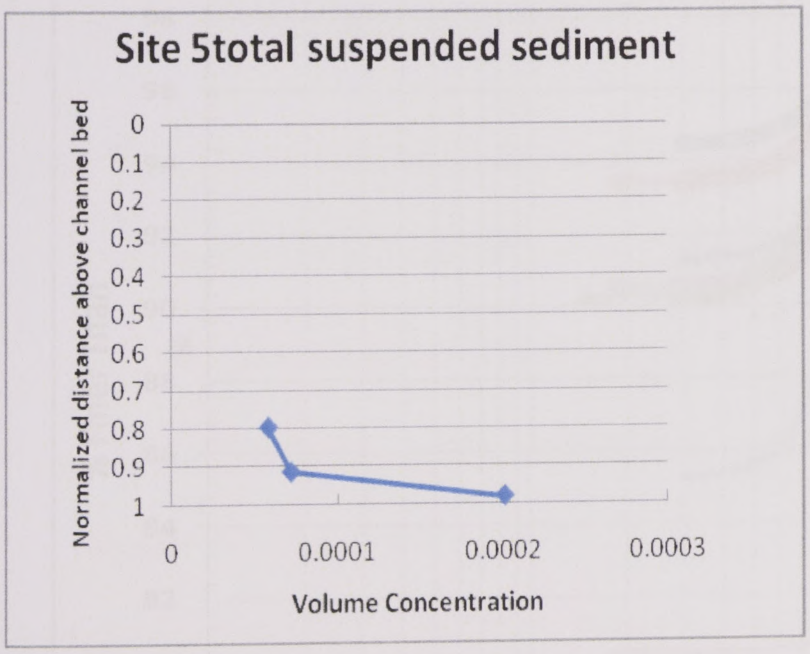


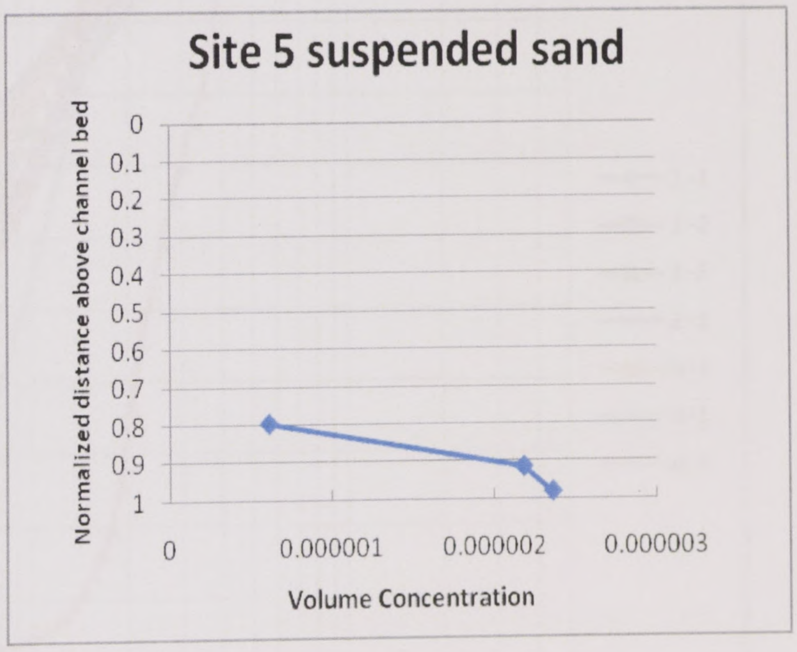

Site 3 total suspended sediment
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.00002
0.00004
0.00006
0.00008
0.0001
Volume Concentration

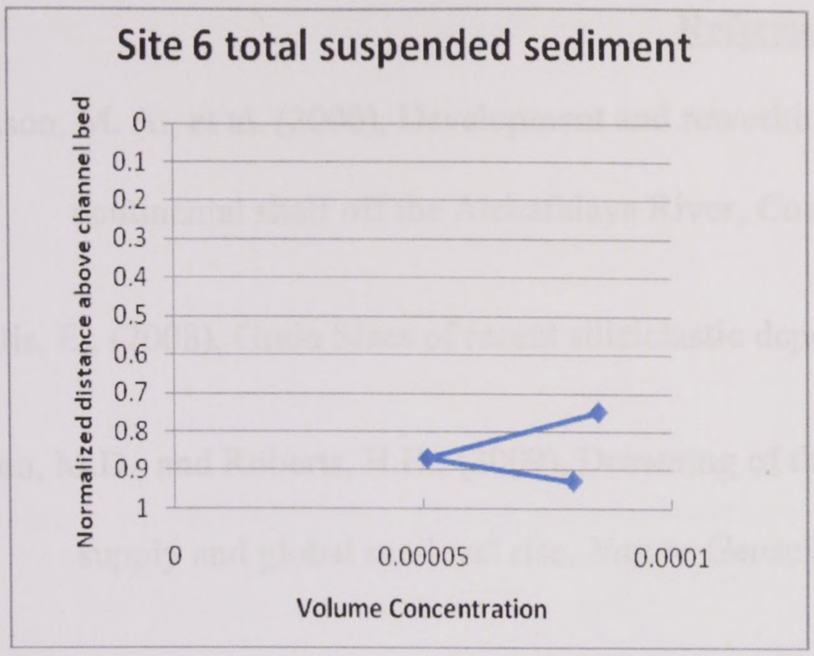

Site 3 suspended sand
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.000002
0.000004
0.000006
Volume Concentration

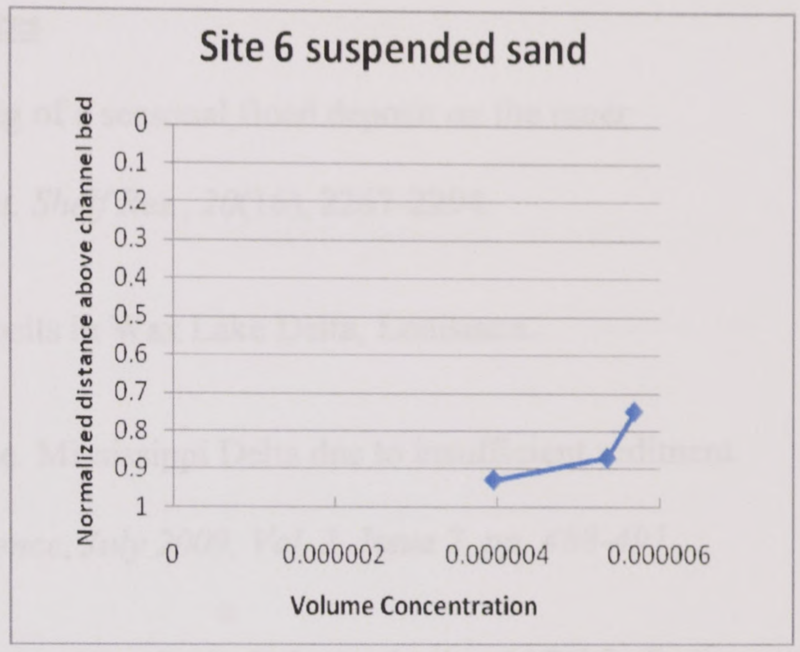

Site 4 total suspended sediment
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.00005
0.0001
0.00015
Volume Concentration


Site 4 suspended sand
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.00001
0.00002
0.00003
Volume Concentration

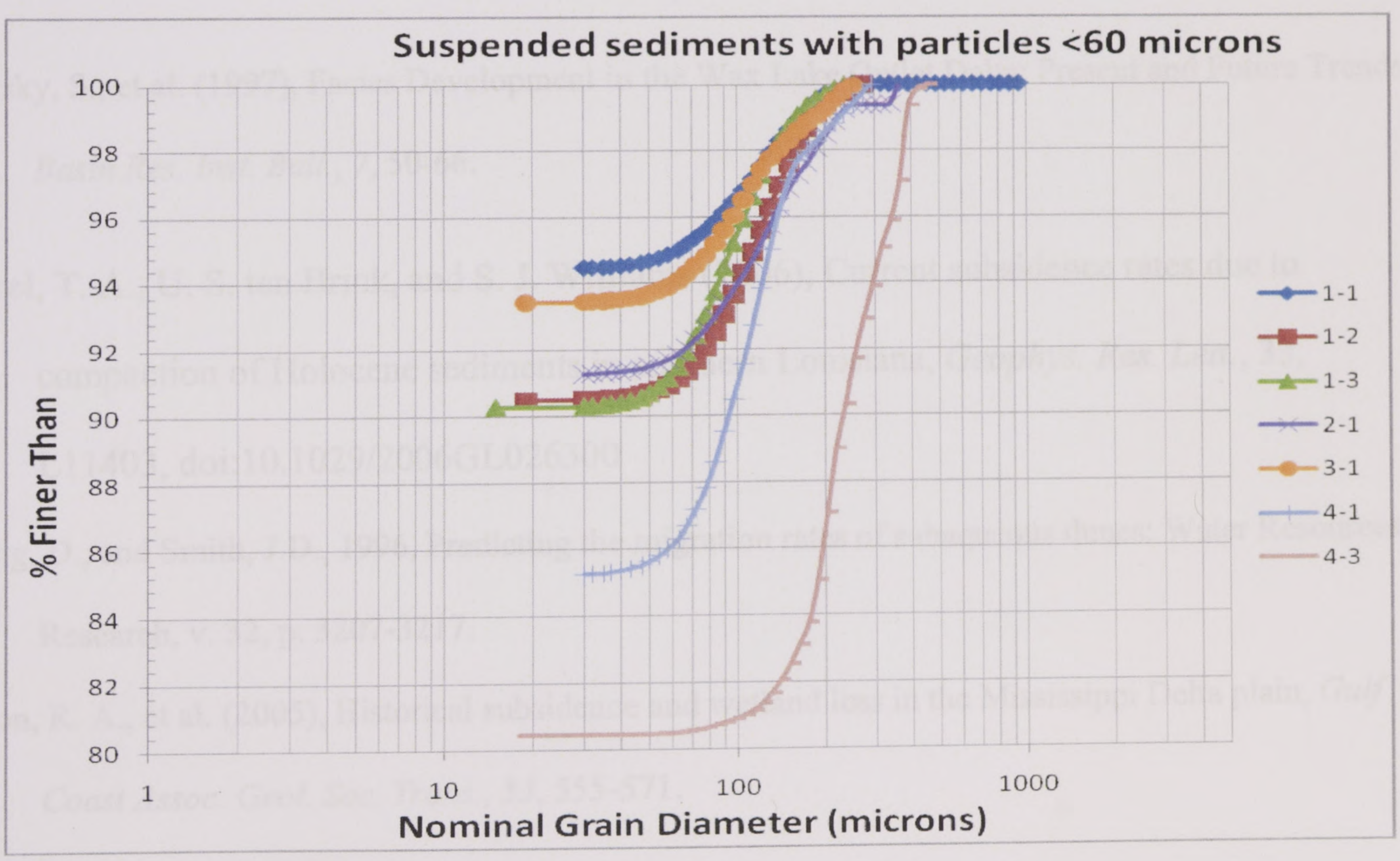

Site 5total suspended sediment
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.0001
0.0002
0.0003
Volume Concentration


Site 5 suspended sand
Normalized distance above channel bed
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.000001
0.000002
0.000003
Volume Concentration





Cumulative grain size distribution plots suspended sands adjusted to include particles <60 μm. Site 2-2 was not included because the amount of mud sized particles was insignificant. The first number on each label refers to the site in which the sample was collected, and the second refers to its position vertically. Each vertical profile begins with the number 1 for the sample closest to the bed, while samples closer to the water surface are sequentially assigned numbers (2-5).



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